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**6. AUTHOR(S)**
Professor Shayne Johnston

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Jackson State University
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Jackson, Mississippi 39217-0460

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**13. ABSTRACT** *(Maximum 200 words)*

The central idea underlying this project was that sideband instabilities could be controlled by optical guiding effects through the radiation of slippage between the electron bunches and the radiation field. However, none of the related six research objectives in the original proposal to AFOSR has been truly completed. The principal advances made during the period of AFOSR support include: the recognition that enhanced radiation pressure can produce disruptive velocity changes in teh presence of slippage (ITR1), the viability of an electron macroparticle model of sideband instabilities (ITR2), and an analysis (including radiative reaction) of the analogous problem of resonance scattering (ITR2). The recognition that electrostatic waves could correlate repelling particles on a length scale much shorter than a wavelength (ITR2) led the PI to an important application to anomalous transport in turbulent plasma (S. Johnston, "Formation of Sub-Debye Microclumps by REsonant Interactions with Electrostatic Turbulence", Bulletin of the American Physical Society, 38 1889 (1993).

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# Final Technical Report
# to the
# Air Force Office of Scientific Research

**CONTRACT NUMBER:** F49620-91-C-0013

**CONTRACTOR:** Jackson State University

**REPORTING PERIOD:** 1 DEC 90 - 30 NOV 93

**RESEARCH TITLE:** "Mathematical Analysis of Three Free-Electron-Laser Issues"

**PRINCIPAL INVESTIGATOR:** Dr. Shayne Johnston
Professor of Physics
Jackson State University

**TECHNICAL CONTRACT MONITOR:** Dr. Arje Nachman
Mathematical and Information Sciences
Air Force Office of Scientific Reaearch
Bolling Air Force Base
DC 20332-6448

## Table of Contents

## Participation of Principal Investigator

The Principal Investigator for this grant, Dr. Shayne Johnston, devoted 50% of his time during the Spring 1993 semester, and 3.0 summer months during Summer 1993, to this grant. The 50% release time from teaching duties was honored by the University and contributed to the continuing support of a Visiting Assistant Professor of Physics.

## Participation of Students

One undergraduate Physics major continued his participation in this research. Mr. Tracy S. Miller returned for his senior year in Fall 1992 and his support from this grant continued into Spring 1993. He received 3.0 hours of academic credit for his participation in this research in Spring 1993 under the auspices of the course PHY 480 (Research Project). Mr. Miller also received travel support from this grant to attend the National Conference on Undergraduate Research held in Salt Lake City, Utah, on March 24-28, 1993. He graduated on schedule from Jackson State University in May, 1993 with a B.S. Degree in Physics. Mr. Miller is currently employed in the Department of Physics and Atmospheric Sciences at Jackson State through a grant to develop an "Integrated Learning Environment" in physics (demonstrations, computers, etc.).

## Computational Physics Research Laboratory

The Computational Physics Research Laboratory, established by the Principal Investigator through research support from AFOSR and DOE, continued to play a vital role in the Department of Physics and Atmospheric Sciences at Jackson State University. This research facility led directly to the current participation of the Principal Investigator as one of four PI's in a large grant funded by ARPA entitled "Interdisciplinary Research Program in High Performance Computational Modeling" (funded by ARPA for the period July 1, 1993 to June 30, 1996; $1,290,000; contract number N00174-93-RC-00004). On a less positive note, the renovation of the building Just Hall of Science through funding from the National Science Foundation has been delayed, and the serious inadequacy of the air-conditioning and ventilation in the computer laboratory continues to be a problem. The renovation is now scheduled to begin in Spring 1995.

## Progress towards Research Objectives

In the following summaries, the two Interim Technical Reports submitted earlier to AFOSR by the Principal Investigator will be abbreviated as ITR1 and ITR2, respectively.

## Project 1: Sideband Instabilities

The central idea underlying this project was that sideband instabilities could be controlled by optical guiding effects through the regulation of slippage between the electron bunches and the radiation field. However, none of the related six research objectives in the original proposal to AFOSR has been truly completed. The principal advances made during the period of AFOSR support include: the recognition that enhanced radiation pressure can produce disruptive velocity changes in the presence of slippage (ITR1), the viability of an electron macroparticle model of sideband instabilities (ITR2), and an analysis (including radiative reaction) of the analogous problem of resonance scattering (ITR2).

The recognition that electrostatic waves could correlate repelling particles on a length scale much shorter than a wavelength (ITR2) led the PI to an important application to anomalous transport in turbulent plasma [S. Johnston, "Formation of Sub-Debye Microclumps by Resonant Interactions with Electrostatic Turbulence", Bulletin of the American Physical Society 38, 1889 (1993)].

## Project 2: Radiative-Reaction Dynamics of Electron Clumps

Project 2 was based upon the Lorentz-Dirac equation and the idea that the force of radiative reaction is scaled up by a relative factor N when a clump of N electrons is treated as a macroparticle. After three years of continued investigation, the PI believes strongly that this idea remains viable and compelling as an approach to creating steady-state extremely-high-power free-electron lasers. The principal advances made during the period of AFOSR support include: the conceptual foundations of the Lorentz-Dirac equation (ITR1, ITR2), enhanced radiation pressure in free-electron lasers (ITR1, ITR2-Appendix C), and laser acceleration of electron clumps (ITR1, ITR2-Appendix C).

Project 3: Orbital-Instability Operating Point

The work of the two undergraduate students who were supported by this grant fell under the auspices of Project 3. The results of these investigations are interesting but incomplete. Please see the Assessment section below. The principal advances made during the period of AFOSR support include: an explicit evaluation of the branch-cut contributions which represent emission from the fugitive electrons at orbital instability, and a careful derivation of the three-dimensional dispersion relation for two concentric thin electron beams in a cylindrical waveguide (i.e., a dual-beam free-electron laser). These lengthy calculations are currently available only in hand-written form and have not been included in this report.

Grant Summary

A. Published Papers:

None. However, please see the Assessment section below.

B. Published Abstracts:

S. Johnston, "Radiative-Reaction Dynamics of Electron Clumps", Bulletin of the American Physical Society 37, 1457 (1992).

C. Meetings Attended:

1. The Principal Investigator attended and presented a poster paper (see ITR2) at the Plasma Divisional Meeting of the American Physical Society held in Seattle, Washington in November 1992.

2. Two undergraduate Physics majors attended the 1992 National Conference for Black Physics Students held at Stanford University in February 1992.

3. One undergraduate Physics major attended the 1993 National Conference on Undergraduate Research held in Salt Lake City, Utah in March 1993.

## Assessment

The Principal Investigator is painfully aware that many of the original research objectives have not been accomplished during the past three years, and that published papers are still forthcoming. Accordingly, the PI has not sought any renewal of funding from AFOSR.

From the point of view of the Principal Investigator, the most significant fruits of his AFOSR support have been indirect as discussed in ITR1 (see Appendix A of this report). In particular, the NSF RCMS undergraduate research mentoring project is thriving, with the PI himself serving as mentor for four students.

Many of the incomplete components of the present grant are ideal as undergraduate research projects. Examples include numerical studies of the Lorentz-Dirac equation, orbital instability in the presence of a guide magnetic field, analysis of the dispersion relation for a dual-beam free-electron laser, nonlinear systems subject to combined forcing and parametric excitation, etc. When such projects lead to publications in the future (and they will!), the PI pledges to acknowledge the support of AFOSR during the initial phases of the work.

Appendix A: Page from Interim Technical Report #1

Some Indirect Benefits of AFOSR Support

Dr. Shayne Johnston's preliminary grant from AFOSR (September 1989 - September 1990) and his current support from both AFOSR and DOE contributed greatly to a "chain reaction" which has seen the Physics Program at Jackson State University truly blossom during the past two years. The perception of the Department as a financially-viable enterprise has led to concrete support from the University Administration. These developments have been immensely gratifying to the PI who has served as Physics Program Coordinator since 1984.

1. The number of tenure-track Physics faculty was doubled from 3 to 6 in Spring 1990.

2. Two Visiting Assistant Professors of Physics were hired in Fall 1990 from purchased-release-time funds.

3. The Computational Physics Research Laboratory was established by Dr. Johnston in Spring 1991.

4. The newly-visible Physics faculty spearheaded the effort to establish JSUNET, the internal campus computer network, and connectivity to the outside world was finally achieved in Fall 1991.

5. The undergraduate research supported by the initial AFOSR grant strengthened the Department's successful proposal to the RCMS program of NSF. The RCMS grant began in Fall 1991 and has had a very positive impact on the recruiting of new Physics majors.

6. The number of Physics majors has increased from a low of only 3 in Fall 1990 to 11 in Fall 1991 to approximately 20 in Spring 1992.

7. On a personal note, Dr. Shayne Johnston received tenure and a promotion to the rank of Professor in Summer 1991. He is currently the only Full Professor in the Department. Dr. Johnston was also chosen by the University as its Faculty Member of the Year for 1992.

# RESTRICTED FUNDS NEW ACCOUNT FORM

## JACKSON STATE UNIVERSITY

## Jackson, Mississippi

**JSU ACCOUNT NUMBER** 334105 **PROJECT DIRECTOR** Dr.S. Johnston

**TITLE OF PROJECT** Mathematical Analysis of Three Free Electron Laser Issue

**FUNDING AGENCY** Air Force Office of Scientific Research **GRANT NO.** F49620-91-C-0013P00002

**FUNDING PERIOD** 10/1/92 to 9/30/93 **AMOUNT OF AWARD $** 74,172.00

**PAYMENT METHOD** Reimbursement **JSU OLD NO.** _____

Year 3 of a 3 year project

| OBJECT CODE | LINE ITEM DESCRIPTION | AMOUNT |
|---|---|---|
| 1356 | Principal Investigator | $ 36,096.00 |
| 2860 | Undergraduate Students | 3,744.00 |
| 3000 | Fringes | 8,664.00 |
| 4110 | Travel | 2,200.00 |
| 5220 | Telephone | 300.00 |
| 6110 | Publication | 993.00 |
| 6130 | Office Supplies | 450.00 |
| 6310 | Scientific Supplies | 450.00 |
| 5910 | Indirect Cost | 21,275.00 |
| | | $ 74,172.00 |

# RESTRICTED FUNDS
# SALARY INFORMATION
# JACKSON STATE UNIVERSITY
# JACKSON, MISSISSIPPI

ACCOUNT NUMBER 334105 PROJECT DIRECTOR Dr. S. Johnston

NAME OF GRANT Mathematical Analysis FUNDING PERIOD 10/01/92 - 9/30/93

| POSITION | NAME | AMOUNT | TYPE OF SERVICE |
|---|---|---|---|
| Principal Investigator | Dr. Shayne Jonhston | $ 21,178 | Release Time 10/92 - 5/93 |
| | | 14,918 | Summer Salary 6/93 - 8/93 |
| | | $ 36,096 | |